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ABSTRACT

The effects of varying amounts of computer assisted instruction (CAI) in mathematics, on the academic performance of 446 fifth and sixth graders scoring below norm on the California Test of Basic Skills (CTBS) were investigated. Independent variables were: (1) beginning-of-year CTBS mathematics pretest score; (2) teacher's verbal ability; (3) years of teacher experience; (4) teacher degree level; (5) student self-expectation; (6) number of CAI sessions that a student had in the year; and (7) intelligence test score. By regression analysis, end-of-year CTBS posttest scores were compared with these independent variables using linear, Cobb-Douglas (homogeneous and nonhomogeneous), and transcendental logarithmic model specifications of student achievement. CAI had a significant and positive impact on achievement in most cases. Typically, 100 5-10 minute CAI sessions--given daily to weekly--can, during the course of a school year, raise a disadvantaged student's grade placement in mathematics by perhaps .3 years over what the achievement gain would have been otherwise. Furthermore, at the present cost of $25 to $75 per student for provision of 100 sessions per year, CAI is substantially less expensive than most alternatives for compensatory education. Advantages and limitations of the Cobb-Douglas and transcendental-logarithmic specifications are also discussed. (Author/CP)

RESEARCH BULLETIN

RB-74-20

THE IMPACT OF VARYING LEVELS OF COMPUTER-ASSISTED INSTRUCTION ON THE ACADEMIC PERFORMANCE OF DISADVANTAGED STUDENTS

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ABSTRACT

This paper examines the effects of varying amounts of computer-assisted instruction (CAI) in mathematics on the academic performance of a sample of 446 disadvantaged 5th and 6th grade students. The students' posttest scores were regressed against their pretest scores, the number of CAI sessions they received, and control variables; the regressions employed linear, Cobb-Douglas (homogeneous and nonhomogeneous), and transcendental logarithmic model specifications. CAI had a significant and positive impact on achievement in most cases; typically 100 CAI sessions of 5 to 10 minutes duration each can, during the course of a school year, raise a disadvantaged student's grade placement in mathematics by perhaps .3 years over what it otherwise would have been. The degree of substitutability of CAI for other school inputs is briefly examined.

INTRODUCTION

The search for effective compensatory education techniques has been discouraging. A substantial fraction of students in the nation's schools fail to achieve at a level adequate to their grade level, and various interventions intended to reverse this failure seem frequently to have had no effect (Jensen, 1969; Picariello, 1969; Wargo, Tallmadge, Michaels, Lipe, and Morris, 1972). Our purpose in this paper is to present results concerning the effectiveness of computer-assisted instruction (CAI) in raising the academic performance of disadvantaged students. We use regression models to relate student achievement to the amount of CAI received and other variables; the results show a positive (though undramatic) effect of CAI for compensatory education.

The type of CAI evaluated in this paper provided a 5 to 10 minute session at a terminal for each child with a frequency of from once a day to once a week. During each session the student responded to 10 to 25 problems and was reinforced concerning the correctness of his response; a summarization of the past history of his responses determined the nature of the next problems he faced. Suppes and Morningstar (1969, 1972) described in more detail this and related types of CAI; it suffices here to say that the technology is well developed and its costs less than for most other compensatory programs (Jamison, Suppes, and Butler, 1970; Jamison, Fletcher, Suppes, and Atkinson, to appear).

A number of previous evaluations exist for this use of CAI and recent surveys of these evaluations (Vinsonhaler and Bass, 1972; Jamison, Suppes, and Wells, to appear) concluded it to be generally effective and particularly so for disadvantaged students. For this paper we gathered substantially more data than was available for previous evaluations; in particular we obtained background characteristics of students and their teachers and the <u>number</u> of CAI sessions each student received. We were thus able to run regressions that would enable us to estimate how varying the number of CAI sessions (and other school characteristics) would affect the academic performance of disadvantaged students.

DATA AND METHODS OF ANALYSIS

Subjects

The data used to analyze the CAI mathematics program were gathered in a predominantly black elementary school district in northern California. The use of students from a relatively homogeneous social group eliminated many of the problems that have confounded data in previous analyses when student background and school resources have been correlated. The data gathered included IQ tests and pre- and posttests in reading and mathematics for the year of the experiment, number of sessions of CAI used in the year, teacher characteristics (teacher verbal ability, years of experience, and degree level), and educational level of the mother and the father of each student. Attitudinal measures for each student and his parents were also obtained. All data were on an individual student basis and it was possible to match students with their teachers. The students receiving CAI were in two schools in this district and students from a third school, not receiving CAI, were used as a control. The sample originally consisted of 511 male and female, fifth and sixth grade students. This was reduced to 446 because of incomplete data. The California Test of Basic Skills (CTBS) subsets in mathematics and reading was administered in the Fall of 1970 and in the Spring of 1971. An examination of the results of the achievement and IQ tests gives some indication of the characteristics of the student population in this analysis; these results appear in Table I. On the CTBS the norm for fifth graders is 5.0

Insert Table I Here

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at the beginning of the year and the norm for sixth graders is 6.0.

An examination of the CTBS scores reveals a deficiency among these students. The fifth graders are 1.2 grades behind in mathematics and 1.5 grades behind the norm group in reading. The gains for the school year are .64 and .57 respectively compared to the norm gain of 1.0. Similar results are observed for the sixth grade students.

Models of Student Achievement

The two basic models[2] used for testing the relationship between the dependent variable, posttest score, and the independent variables are the commonly used linear model and the Cobb-Douglas or log-log model. The important differences in the use of the two models are related to the implicit assumptions of marginal productivity and elasticity of substitution of resource variables.

The linear model takes the general form:

$$Y = b_o + \sum_{i=1}^{n} b_i X_i ,$$

where Y is the dependent variable and the X_is are the independent variables.

The general form of the Cobb-Douglas model is:

$$Y = \beta_o \prod_{i=1}^{n} X_i^{\beta_i} .$$

If logarithms are taken, this equation becomes linear in the logs. Linear regression techniques are used for estimating both models. The Cobb-Douglas model must be transformed to logarithmic form before using linear regression.

The one alteration of the Cobb-Douglas model is the use of the dummy variable for teacher degree level. When this variable is used in the linear model it is scaled with a value of zero for teachers with only a bachelor's degree and a value of one for teachers who also possess the master's degree. To obtain the same type effect with the Cobb-Douglas model one cannot simply enter teacher degree level since this would cause the value of output to be zero whenever the teacher possesses only the bachelor's degree. The variable used to represent teacher degree level is the logarithmic base raised to the power $\beta_i X_i$, where X_i is the dummy variable with the same values as defined for the linear model. The Cobb-Douglas model then takes the following form when a dummy variable is included:

$$Y = \alpha e^{\beta_1 X_1} X_2^{\beta_2} X_3^{\beta_3} \ldots .$$

When $X_1 = 0$,

$$Y = \alpha X_2^{\beta_2} X_3^{\beta_3} \ldots \quad , \text{and}$$

when $X_1 = 1$,

$$Y = \alpha e^{\beta_1} X_2^{\beta_2} X_3^{\beta_3} \ldots .$$

RESULTS AND DISCUSSION

In this section we first undertake several straightforward tests of CAI effectiveness, then examine the extent to which teacher characteristics affect the amount of CAI their students receive. We then present our basic regressions and their results for teacher and student variables. The final subsection deals in more detail with the impact of varying the level of CAI for individual students.

Simple Tests of CAI Effectiveness

As a first test for the effectiveness of CAI simple statistical tests are used to test for the significance of differences in mean gain scores between CAI and non-CAI groups stratified by grade and sex for the CTBS in mathematics and reading; Tables II and III show these results.

Insert Tables II & III Here

For mathematics the use of CAI has a significant effect on achievement for all groups but fifth grade girls. In all cases where there is a significant difference in gain scores the difference is due to a higher gain for CAI students as opposed to non-CAI students. If all other inputs were held constant, then the difference in gain scores might be attributable to the average number of CAI sessions that the students had. Inputs which tend to favor non-CAI students over CAI students (higher mean values) include teacher verbal score (score on the 100 point Quick Word Test) and teacher years of experience.

Scaled variables for teacher degree level, mother and father education level, and mother, father, and student expectations tenc to favor CAI students.

An interesting result observable from Table III is the significance of differences in reading score gain for two of the stratifications. Fifth grade boys and sixth grade girls receiving CAI had significantly higher gains than students not receiving mathematics CAI. The average gains were higher for CAI students in the other two groups, but were not statistically significant.

In the previous school year all students had received mathematics CAI and many had received CAI in reading. Thus the existence of an effect in the second year helps to alleviate the concern that the effectiveness of CAI is due to a Hawthorne effect and that CAI is only effective until the novelty disappears. The novelty of CAI usage is probably dispelled by the second year of implementation and accepted as a normal part of the learning environment. During the school year being analyzed only a few students in one of the mathematics CAI schools had received reading CAI for remedial work. It is unlikely that the positive gains in reading experienced by the CAI groups could be attributed to the few students receiving remedial work. The existence of an effect on reading in the year following CAI usage may indicate a lagged effect on achievement scores.

A possible hypothesis for the continuance of an effect on reading score is that students who are currently receiving CAI have higher values of self-expectation than students who do not receive it, and that reading scores are related to self-expectation. For each of the groups above the variable for self-expectation was regressed against a dummy variable representing the use of CAI for each student. For all groups the relationship was insignificant. Based on the variable used to measure self-expectation in this data sample we are unable to prove the hypothesis of a transfer mechanism occurring through an expectational variable. It is possible that better measures of student expectations and self-efficacy would lead to an acceptance of the hypothesis. Interestingly, when each group is stratified into CAI and non-CAI students there is a significant relationship between self-expectation and the number of CAI sessions a student was exposed to for all groups but fifth grade boys. However, Hess and Tenezakis (1970) and Smith and Hess (1972) concluded that no difference in mean values for a wide variety of attitudinal measures could be uncovered between CAI groups and non-CAI groups.

The higher gains for CAI students in reading could not be attributed to better teachers or brighter students in the CAI classrooms. An examination of mean pretest and IQ scores and means of teacher characteristics reveals no advantage to CAI students. With the exception of math scores for sixth grade boys the mean scores are higher for non-CAI students. Means are generally higher for teacher characteristics for non-CAI students, although regression analysis revealed an apparent disadvantage for higher teacher verbal scores (in contrast to most results concerning this variable, e.g., Bowles and Levin, 1968, and Hanushek, 1970).

Teacher Control of CAI

Since there is a variation in the number of CAI sessions for the students, it is of interest to determine if this variation can be accounted for by some measurable teacher characteristic. For this purpose separate regressions were run for each of the groups and each of the teacher characteristics. Table IV summarizes the results for tests of the hypotheses that either teacher intelligence (as measured by the verbal test), teacher experience, or teacher degree level (Master's or Bachelor's) can account for some of the variation in CAI sessions received by the students. Separate equations were estimated for each of the teacher characteristics as an independent variable. Number of sessions of CAI was the dependent variable for all equations reported in Table IV.

Insert Table IV Here

For all groups there is a wide range of CAI sessions as observed from the means and standard deviations for CAISES. The hypothesis that more intelligent teachers or teachers with more experience will use greater amounts of CAI for their students is confirmed for sixth grade teachers but not for fifth grade teachers. For the sixth grade an additional point of teacher verbal score leads to approximately two more sessions of CAI for both boys and girls and an additional year of experience leads to 3.6 more sessions for girls and 2.5 more sessions for boys. While TEAVER and TEAEXP are not significant in the relationships for fifth graders it is of interest to note the negative sign on the coefficient in three of the cases.

In the significant relationships for TEAVER and TEAEXP r^2 is high, but not all of the variation in CAI sessions has been accounted for. Other possible factors affecting number of sessions include student absenteeism and how teachers assign students to the terminal. We do not have data for student attendance, and without classroom observations we cannot be sure of the decision process of the teacher. Teachers sometimes commented that preventing a student from using the computer terminal was used for discipline.

Student Achievement Models

In our regression analyses the str[illegible]on by grade, sex, and CAI usage was maintained so that the e[illegible]t of CAI for different groups could be discussed. The output measure used in these regression analyses was MA (CTBS mathematics posttest score). The independent or input variables included:

MB = CTBS mathematics pretest score.

TEAVER = score of teacher on 100 point verbal test,

TEAEXP = years of teacher experience,

TEADEG = scaled variable for teacher degree level,

SELFEX = scaled variable for student response to self-efficacy,

CAISES = number of sessions of CAI that a student had in the year, and

IQ = intelligence test score.

Correlation matrices with means and standard deviations of the variables in the regression equations are included in the appendix. Other variables[3] which were measured are not included in the present analysis for two reasons. First, when some of the variables were included in the regression analysis they were found to be insignificant and did not alter R^2. Second, the variable MB embodies most of the effects of previous education and IQ embodies most of the effects of background variables. Benson et al. (1965), Burkhead, Fox, and Holland (1967) and Katzman (1971) found high degrees of correlation between various measures of student socioeconomic status and IQ scores.

Tables V - VIII present the basic regression results.

Insert Tables V, VI, VII & VIII Here

Prior to an analysis of the size of the coefficients and their meanings an examination of the change in the coefficient and its significance for any one group reveals some of the possible effects of misspecification of the model when excluded variables are correlated with included variables. In general if an excluded variable is positively correlated with the dependent variable and with one of the included variables we would expect the coefficient of the included variable to include the effects of the excluded variable. When the excluded variable is included we would expect the coefficient of the other variable to be reduced. This phenomenon is observable in comparison of models 2 and 5 for fifth grade boys and girls. The difference between these models is the inclusion of TEADEG (teacher degree level) in model 5. This variable is positively correlated with posttest score and CAISES and the coefficient of CAISES is lower in model 5 than model 2 for linear and log models for both groups.

The other possible occurrence is an excluded variable being negatively correlated with the dependent variable and positively correlated with an included variable or positively correlated with the dependent variable and negatively correlated with an included variable. In this case when the variable is excluded we would expect the included variable to pick up the effects of that variable and for the coefficient to be lower and possibly statistically insignificant. When the excluded variable is included we would expect the coefficient of the other variable to increase and possibly become statistically significant. This may be observed in a comparison of models 1 and 2 for fifth grade boys and girls. In model 2 IQ score and SELFEX (the attitude variable) are included. IQ score is not correlated with CAISES or the posttest score, but SELFEX is positively correlated with CAISES and negatively correlated with posttest score. When it is included the coefficient of CAISES rises in all cases and for fifth grade girls it becomes significant at low levels of confidence.

No attempt was made at stratification by socioeconomic status as Carnoy (1971) and Hanushek (1970) did in their studies because of the relatively homogeneous nature of the school population.

For all models and all groups there is little difference between the statistical fit of linear models and Cobb-Douglas models. Equations for fifth grade girls slightly favor the Cobb-Douglas specification and for the other groups the linear model is slightly favored. However, the differences appear to be insufficient to warrant choosing one model specification over the other.

Sex. The first item noticed from an examination of Tables V-VIII is the differential impact of school resource variables by sex of student. For the fifth grade students number of CAI sessions is highly significant for boys in all models and is significant in the log equations for girls. In a model by model comparison the coefficient of CAISES has a larger value for the boys. For sixth graders there is no school resource variable which is significantly related to the achievement of the girls; number of sessions of CAI is significant at low levels of confidence for the boys. Again for each model the coefficient of CAISES has a higher value for boys than for girls.

Pretest. As can be expected pretest scores are highly significant in determining posttest scores in all cases. For example, for fifth grade boys an increase in pretest score of one grade equivalent will raise posttest scores by one grade equivalent. The size of the coefficient is indicative of how well a student on the average with a higher pretest score will perform in the current school year. To the extent that pretest score embodies previous learning situations we can measure the effect of this previous learning. Pretest scores would be beneficial to policy decisions if stratification by pretest scores led to different results for the models for different groups. In this analysis a stratification by pretest score was undertaken for fifth grade boys with CAI. Due to the small sample size once a group is stratified, there is a large dependence of regression results based on the arbitrary boundaries set for group stratifications and the results do not contain information of value. The study by Suppes, Fletcher, Zanotti, Lorton, and Searle (1973) was more conducive to this type of analysis. In their experimentation they were able to vary number of CAI sessions based on pretest scores. The sample size in their analysis was larger and they were able to assure a variance in sessions for each of the groups.

IQ. With the exception of the log models for sixth grade girls, IQ score was found to be insignificant. While we would expect intelligence level to be significantly related to posttest scores there are several possible explanations for this lack of significance. First, to some extent, the effects of intelligence on test scores is partially embodied in pretest scores. Second, as previously mentioned, there has been a large correlation between IQ and other background variables in education analyses. In this study with students with similar backgrounds rather than the diverse backgrounds of other studies, background characteristics do not have a significant relationship with test scores. A third possible explanation is that while intelligence of students may well be related to achievement, the IQ test used may not adequately measure intelligence of these students.

Student self-expectation. The results on the student expectation variable in the models is interesting.[4] We would expect students with higher degrees of confidence to perform better in achievement scores than students with lower degrees of confidence. For fifth graders the relationship is significant and negative. Students with higher confidence levels perform less well than students with lower confidence levels. For sixth graders the relationship is generally insignificant but positive. These results may possibly be attributed to the lack of a good measure of student expectations and self-efficacy or difficulty with the question's containing a double negative.

Teacher characteristics. We chose to examine separate models for each of the teacher characteristics because of varying degrees of correlation between these variables for each of the student groups. The teacher degree variable is excluded for sixth graders since no teacher in the sixth grade possessed a Master's degree. Our hypothesis for each of the variables would be a positive correlation between each of the teacher characteristics and student achievement. This hypothesis is relevant to the actual situation in education since teachers are rewarded for more experience and higher degree levels with higher salaries. In terms of efficiency it would be desirable to have rewards related to performance, and student mathematics achievement is certainly one logical measure of teacher performance.

For teacher degree level the hypothesis is confirmed for both fifth grade boys and girls. On the average, possession of the Master's degree leads to an increase in achievement score by .2 grade equivalents for both groups.

The results for teacher experience vary for each group. For sixth grade boys and girls the coefficient is not significant, but it is positive for girls and negative for boys. For fifth grade girls the coefficient is negative and significant at a low confidence level in the linear model. The coefficient is -.01 in the linear model and represents the decrease in posttest score for each year of teacher experience. For fifth grade boys the result is a mildly significant positive relationship. We expect that each year of experience would increase teaching effectiveness at a diminishing rate, i.e., an additional year of experience is more important to a newer teacher than the more experienced teacher.

Teacher verbal score is only significant for fifth grade girls. For the other groups the insignificant coefficient takes a positive sign for fifth grade boys and a negative sign for both groups of sixth graders. The relationship is highly significant and negative for the fifth grade girls with a coefficient of -.0083 in the linear model and -.0888 in the log model. The teacher verbal score was significant in estimations of student reading score with large positive coefficients (e.g., .011 for sixth grade girls and .052 for sixth grade boys). For mathematics achievement a test of teacher mathematical ability may have been more relevant. A possible explanation of the negative correlation is that teachers with higher degrees of verbal ability spend more time in subjects they may feel more confident in, e.g., reading. A test of this hypothesis would require either classroom observations or a teacher report of relative or absolute amounts of time spent on various subjects. Without this information it is difficult to explain with complete confidence the negative relationships observed.

The Effectiveness of Computer-Assisted Instruction

Effectiveness. For mathematics achievement the most obvious hypothesis to test is that greater amounts of CAI contributed to higher test scores in mathematics. If this hypothesis were true we would expect positive, significant coefficients for CAISES (number of sessions of CAI per year) in our models. The hypothesis is confirmed for fifth grade boys in all models, in the log models for fifth grade girls at high levels of confidence (99% or 95%), and at lower levels of confidence for the linear models and all models for sixth grade boys. The hypothesis is not confirmed for sixth grade girls in any of the models.

CAISES was consistently significant at high levels in all models for fifth grade boys; our comments focus on that subset of the sample, but could be applied to the other subsets as well. In the linear models the coefficient of CAISES is approximately .004. Each session of CAI increases student mathematics achievement by .004 grade equivalents. The range of CAI sessions for these students was 3 to 159 with a mean of 80 and a standard deviation of 43. If this coefficient is valid over the entire range of the variable as the use of a linear model assumes, then the student with 100 sessions will have increased his posttest score by .4 grade equivalents. This is an impressive gain considering that 100 sessions represents the usage of the computer on an average of slightly over every other day for a 5 to 10 minute session. It was not possible to test whether the time sequence of presentation of CAI was important in determining achievement scores.

By an examination of coefficients of other variables we can discuss the degree of substitution possible between CAI and other input variables. Teacher experience and attainment of a Master's degree were found to be significant. In the linear model the coefficient on teacher experience is .0091. Decreasing teacher experience by one year requires only 2 1/4 CAI sessions to compensate for the loss in student mathematics score. If we wish to substitute teachers with Bachelor's degrees for teachers with Master's degrees student mathematics achievement would fall by .2 grade equivalents, on the average. To compensate for this decrease, an additional 57 sessions of CAI would be required. Any real world decision on substitution of inputs would necessitate the introduction of cost data and an examination of the effects on other outputs, both cognitive and noncognitive, to determine the advisability of changing teacher characteristics.

While it is possible that stratification by pretest score would reveal different coefficients and different degrees of significance for the CAI variable, it is still possible to discuss the trade-off between CAI sessions and pretest scores. For fifth grade boys an additional score of 1.0 grade equivalents on pretest scores contributes 1.0 grade equivalents to posttest scores, on the average. If the coefficient on CAISES of .004 were valid for a larger range of CAI sessions than actually observed, it would require 225 sessions of CAI to compensate for a one year deficiency in achievement scores.

<u>Diminishing marginal product</u>. The advantage of the use of the Cobb-Douglas function is that it models the diminishing marginal productivity which would be expected to occur for teacher experience and probably for CAI as well. One disadvantage of the use of this function is that it implies a constant <u>elasticity</u> of output, i.e., regardless of the level of any of the inputs, a one percent increase

in the value of an input will result in a fixed percentage increase in the value of the output variable. The elasticity of output for any input is the exponent of the input in the function and this is the estimated coefficient in the regression analysis with the variables converted to logarithms. Another disadvantage is that if any of the inputs is zero, then the value of the output is also zero.[5] In the case of CAI sessions students who do not receive CAI would have an output that cannot be estimated from our equations. For this reason we estimate equations for CAI and non-CAI students separately, and the coefficients discussed for CAI sessions are valid only for those students receiving a positive amount of CAI.

The effects of the assumption of diminishing marginal productivity is quite pronounced in an analysis of input substitutions. As we stated in the previous section, using the linear model, a year of teaching experience is equivalent to 2 1/4 sessions of CAI regardless of the total number of years of experience or CAI sessions. With the Cobb-Douglas model the total numbers are relevant to the substitution decisions. For example, approximately 100 sessions of CAI would be necessary to compensate for a change of teaching experience from 4 years to 3 years while only 6 sessions are needed if the change is from 9 years to 8 years.

There are alternatives to the Cobb-Douglas function that would allow estimation of diminishing marginal productivity in an essentially linear equation. For example, we could take the teacher experience variable and categorize it into dummy variables representing different amounts of experience (e.g., 0-1 years, 2-5 years, 6-15 years, etc. or some other division). The difference in coefficients between two category variables would then represent the additional effect from moving into the next higher category of experience. Diminishing marginal productivity would be evident if either the size of the coefficients varied from higher to lower values or the significance of coefficients on the higher experience variables diminished.

Several equations were estimated using scaled variables for CAI sessions per year and teacher experience in linear models for fifth grade boys with CAI. Teacher experience was divided into three variables for ten years of experience (0-10, 10-20 and 20-30) and also into six variables in the expectation that bigger differences would be uncovered in earlier years. R^2 was slightly higher than the linear model with teacher experience entered only as a single continuous variable. Most of the coefficients were significant and positive. Diminishing marginal productivity was observed although not at the rate predicted by the Cobb-Douglas function. The division of CAI sessions per year was undertaken in two ways. The first division was into groups of 20 sessions (0-20, 21-40, 41-60, etc.) and the second division was made so that each group had the same number of students. In both cases many of the CAI session dummy variables were positively significant,but diminishing marginal productivity was not consistently observed and the results were highly dependent on the stratification chosen. The results of this analysis indicate that the concept of diminishing marginal productivity is justifiable although the Cobb-Douglas function may not have been the best representation of it.

Transcendental-logarithmic specification. A final specification of production functions, the transcendental-logarithmic (trans-log) function, formulated by Jorgenson, Christensen, and Lau (1973) was also tested. The advantages of this specification are the greater degree of generality and the possibility of varying elasticities of substitution between different input pairs. The existence of interaction terms between each pair of inputs provides for the greater degree of generality. The form of the production function is:

$$Y = \beta_o \left[\prod_{i=1}^{n} X_i^{\beta_i} \right] \left[\prod_{i=1}^{n} X_i^{1/2\left(\sum_{j=1}^{n} \gamma_{ij} \ln X_i \right)} \right] .$$

The equation is estimated by taking logarithms of both sides and the form of the estimated equation is:

$$\ln Y = \ln \beta_o + \sum_{i=1}^{n} \beta_i \ln X_i + 1/2 \sum_{i=1}^{n} \sum_{j=1}^{n} \gamma_{ij} \ln X_i \ln X_j .$$

The Cobb-Douglas function that we previously estimated is the special case of the trans-log that results if $\gamma_{ij} = 0$ for all i,j.

With our data there was a difficulty of multicollinearity between many of the interaction terms and the single input terms used to calculate the interaction terms. As expected, the multicollinearity problem is particularly acute between variables such as $\ln X_i$ and $(\ln X_i) \cdot (\ln X_i)$. When all of the terms specified by the production function are entered into the regression analysis multicollinearity confounds the problem of determining the significant variables. Using step-wise regression we analyzed various forms predicted by the trans-log function in which many of the terms are eliminated from the final form.

We chose fifth grade males with CAI and selected four inputs -- pretest score, CAI sessions per year, student self-efficacy, and teacher experience-- to analyze the trans-log function. The equation reported below is representative of our results. The t values are in parentheses below the estimated coefficient and all variables are in log form.

$$\begin{aligned} MA = .7519 &+ \underset{(14.91)}{.3362\ MB^2} + \underset{(3.19)}{.0084\ CAISES^2} - \underset{(2.03)}{.1060\ SELFEX^2} + \underset{(1.84)}{.2677\ TEAEXP^2} \\ &- \underset{(1.72)}{.0547\ (CAISES)(TEAEXP)}\ . \end{aligned}$$

$$R^2 = .7597\ .$$

There is a slight improvement in R^2 as compared with the Cobb-Douglas model, although it is still lower than the R^2 in the linear models. The marginal product of CAI sessions is calculated by evaluating the partial derivative of posttest score with respect to CAI sessions and assuming all variables at the mean values. We compared the marginal product of CAI with that of the Cobb-Douglas function and found very small differences between the marginal product functions. This, combined with the multicollinearity problems in estimating the trans-log function, indicates a limited usefulness of this function in describing the relationship of the variables in this analysis.

CONCLUSION

In this paper we have examined in some detail the effect of small amounts of CAI in mathematics on a relatively homogeneous group of 446 educationally disadvantaged elementary school students. The results are encouraging: 100 CAI sessions of 5 to 10 minutes duration each can, during the course of a school year, raise a disadvantaged student's grade placement in mathematics by perhaps .3 years over what it otherwise would have been. The estimated amount varies for our different subsamples and the different models we estimated; nonetheless, approximately this level of gain appears to be possible. More frequent CAI sessions would result in greater gain, but not proportionately so. Our work provides improved models of the impact of CAI on disadvantaged students and confirms the generally positive conclusions of earlier evaluations.

We thus cannot concur in the pessimistic assessment of the possibility of compensatory education expressed by Carnoy (1972) and several of the authors referred to in the Introduction to this paper. The present evidence indicates CAI to be replicably effective and its present cost (perhaps \$25 to \$75 per student for provision of 100 sessions per year) is substantially less than most alternatives for compensatory education. While the present evidence is favorable toward CAI much remains to be learned. What are its long term cognitive effects? How might provision of CAI in different subject matters interact in producing cognitive growth? If CAI can be used to bring the rate of cognitive growth of disadvantaged children up to the present national averages, what will be the effects on their attitudes and self-expectations? Can CAI shape attitudes and expectations in ways controlled by the programmers? The short term promise of CAI can only be validated by research into these long term effects.

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FOOTNOTES

[1]This research was supported by the National Science Foundation through Grant EC-37762 to the Educational Testing Service, Princeton, New Jersey and Grant NSF-GJ-443X3 to the Institute for Mathematical Studies in the Social Sciences, Stanford University, Stanford, California.

[2]The structure and empirical results of a third model of production formulated by Jorgenson, Christensen, and Lau (1973) are discussed at the end of the third section.

[3]Other variables considered were the educational level of the mother and father, the aspiration level for student of the mother and father, the number of books in the home, and student age.

[4]The question used for this variable is "People like me do not have much of a chance to be successful" (0-agree; 1-not sure; 2-disagree).

[5]To overcome this inherent difficulty in the use of the Cobb-Douglas function an attempt was made to estimate a nonhomogeneous form of the function. The nonhomogeneous form was estimated by adding a constant to CAI sessions per year to represent the amount of output that would be produced in the absence of CAI. Constants ranging from a value of 1 to 100 were added to CAI sessions before the logarithms were taken and the equation estimated. R^2 varied very little for the different constants, ranging from .7431 for the constant of 1 to .7449 for the constant of 100 with a maximum of .7459 for 25. As to be expected, the value of the estimated coefficient

increases as the constant increases, but the value of the marginal product is also dependent on the constant chosen and with the small range in R^2 there is no logical basis for choosing a constant. Another method for allowing for positive output when a nonessential input such as CAI is used at a zero level may be more fruitful.

TABLE I

Means and Standard Deviations for California Test of Basic Skills and IQ Tests by Grade

Group	Math Pretest		Math gain		Reading Pretest		Reading gain		IQ	
	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
Fifth grade	3.84	.92	.64	.57	3.54	1.04	.57	.66	87.3	10.5
Sixth grade	4.21	1.11	.48	.61	3.99	1.17	.72	.82	87.6	9.4

TABLE II

Average Grade-placement and Gain Scores on the California Test

of Basic Skill, Mathematics Subset

Group	Pretest		Posttest		Gain		t for gain differences
	CAI	non-CAI	CAI	non-CAI	CAI	non-CAI	
Fifth grade girls	3.91(97)[a]	4.19(41)	4.61	4.93	.70	.74	.36
Fifth grade boys	3.54(89)	3.73(45)	4.23	4.17	.69	.44	2.41**
Sixth grade boys	3.84(63)	4.87(57)	4.57	5.31	.73	.44	2.32**
Sixth grade boys	4.17(37)	4.03(17)	4.82	4.13	.65	.10	3.56***

[a]Numbers in parentheses are numbers of students.

**Significant at 95% ($t \geq 2.0$).

***Significant at 99% ($t \geq 2.8$).

TABLE III

Average Grade-placement and Gain Scores on the California Test of Basic Skills, Reading Subset

Group	Pretest		Posttest		Gain		t for gain differences
	CAI	non-CAI	CAI	non-CAI	CAI	non-CAI	
Fifth grade girls	3.52(97)[a]	3.94(41)	4.23	4.59	.71	.65	.44
Fifth grade girls	3.11(89)	3.61(45)	3.77	3.87	.66	.26	3.33***
Sixth grade girls	3.86(63)	4.75(57)	4.76	5.26	.89	.51	2.76***
Sixth grade boys	3.81(37)	3.52(17)	4.69	4.11	.88	.59	1.05

[a]Numbers in parentheses are numbers of students.

***Significant at 99% ($t \geq 2.8$).

TABLE IV

Relationship Between CAI Sessions and Teacher Characteristics

by Student Group

Group	CAISES[a]		TEAVER[b]			TEAEXP[c]			TEADEG[d]		
	Mean	S.D.	b[e]	t	R^2	b	t	R^2	b	t	R^2
Fifth grade girls	85.0	37.6	-.11	.13	.003	.48	.75	.015	34.85	5.03	.219***
Fifth grade boys	79.9	42.5	-.48	1.60	.035*	-.14	.05	.001	18.67	2.18	.047**
Sixth grade girls	59.2	36.4	1.79	11.43	.679***	3.60	5.58	.339***	--[f]	--	--
Sixth grade boys	60.2	34.6	2.12	9.78	.532***	2.48	6.17	.463***	--	--	--

[a]Number of sessions of CAI.

[b]Teacher score on 100 point verbal test.

[c]Years of teaching experience.

[d]Teacher degree level.

[e]Regression coefficient.

[f]Regression not possible since teachers in these groups were all at same degree level.

*Significant at 85% ($t \geq 1.5$) or 90% ($t \geq 1.7$).

**Significant at 95% ($t \geq 2.0$).

***Significant at 99% ($t \geq 2.8$).

TABLE V

Effects on Mathematics Posttest Scores for Fifth Grade Girls
with Linear and Cobb-Douglas (Log) Models

Variable	Model 1	Model 2	Model 3	Model 4	Model 5
			Linear models		
MB	.9518***a (.0626)	.9277*** (.0642)	.9116*** (.0622)	.8999*** (.0650)	.9345*** (.0634)
CAISES	.0012 (.0013)	.0019* (.0012)	.0017* (.0010)	.0024* (.0014)	.0004 (.0016)
SELFEX		-.1754** (.0840)	-.1742** (.0810)	-.1885** (.0831)	-.1404* (.0848)
IQ		.0028 (.0052)	.0031 (.0050)	.0023 (.0650)	.0036 (.0051)
TEAVER			-.0083*** (.0029)		
TEAEXP				-.0101** (.0051)	
TEADEG					.2225* (.1173)
R^2 Constant	.713 .789	.727 .857	.748 1.427	.737 1.123	.737 .294
			Cobb-Douglas (log) models		
MBLOG	.8229*** (.0533)	.8127*** (.0539)	.7985*** (.0531)	.7977*** (.0556)	.8156*** (.0542)
CAISESLOG	.0306* (.0207)	.0481** (.0216)	.0439** (.0212)	.0496** (.0219)	.0310 (.0244)
SELFEXLOG		-.0834** (.0361)	-.0771** (.0358)	-.0874** (.0372)	-.0702* (.0373)
IQLOG		.0271 (.0793)	.0270 (.0781)	.0265 (.0802)	.0349 (.0799)
TEAVERLOG			-.0888** (.0358)		
TEAEXPLOG				-.0112 (.0105)	
TEADEGLOG					.0350* (.0234)
R^2 Constant	.724 .271	.732 .361	.755 .528	.741 .171	.743 .083

*Significant at 85% ($t \geq 1.5$) or 90% ($t \geq 1.7$).

**Significant at 95% ($t \geq 2.0$).

***Significant at 99% ($t \geq 2.8$).

[a]Regression coefficient; standard error of coefficient is in parentheses.

TABLE VI

Effects on Mathematics Posttest Scores for Fifth Grade Boys with Linear and Cobb-Douglas (Log) Models

Variable	Model 1	Model 2	Model 3	Model 4	Model 5
Linear models					
MB	.9877***[a] (.0663)	1.0181*** (.0014)	1.0165*** (.0733)	1.0183*** (.0725)	1.0260*** (.0725)
CAISES	.0037*** (.0012)	.0040*** (.0012)	.0043*** (.0012)	.0041*** (.0012)	.0035*** (.0012)
SELFEX		-.1541** (.0737)	-.1622** (.0738)	-.1566** (.0728)	-.1476** (.0728)
IQ		.0014 (.0062)	.0017 (.0062)	.0012 (.0061)	.0001 (.0061)
TEAVEP			.0038 (.0032)		
TEAEXP				.0091* (.0051)	
TEADEG					.2003* (.1076)
R^2	.749	.762	.766	.771	.772
Constant	.424	.405	.492	.316	.031
Cobb-Douglas (log) models					
MBLOG	.7805*** (.0562)	.7977*** (.0613)	.7987*** (.0627)	.8052*** (.0620)	.8085*** (.0623)
CAISESLOG	.0497*** (.0158)	.0548*** (.0161)	.0563*** (.0162)	.0572*** (.0159)	.0465*** (.0161)
SELFEXLOG		-.0732* (.0405)	-.0701* (.0409)	-.0643* (.0400)	-.0617* (.0401)
IQLOG		.0451 (.1314)	.0327 (.1295)	.0073 (.1283)	-.0007 (.1292)
TEAVERLOG			.0440 (.0409)		
TEAEXPLOG				.0195* (.0108)	
TEADEGLOG					.0452* (.0263)
R^2	.723	.730	.735	.742	.741
Constant	.242	.157	-.096	.140	.155

*Significant at 85% ($t \geq 1.5$) or 90% ($t \geq 1.7$).

**Significant at 95% ($t \geq 2.0$).

***Significant at 99% ($t \geq 2.8$).

[a]Regression coefficient; standard error of coefficient is in parentheses.

TABLE VII

Effects on Mathematics Posttest Scores for Sixth Grade Girls with Linear and Cobb-Douglas (Log) Models

Variable	Model 1	Model 2	Model 3	Model 4[b]
		Linear models		
MB	.8752***[a] (.0785)	.8536*** (.1005)	.8524*** (.1012)	.8564*** (.1089)
CAISES	.0012 (.0021)	.0003 (.0023)	.0016 (.0039)	.0002 (.0028)
SELFEX		.1092 (.1245)	.1230 (.1295)	.1055 (.1365)
IQ		.0054 (.0090)	.0057 (.0091)	.0053 (.0093)
TEAVER			-.0039 (.0088)	
TEAEXP				.0014 (.0204)
R^2	.676	.684	.685	.684
Constant	1.145	.661	.817	.665
		Cobb-Douglas (log) models		
MBLOG	.6868*** (.0659)	.6475*** (.1395)	.6327*** (.1782)	.6374*** (.0822)
CAISESLOG	.0203 (.0215)	.0296 (.0328)	.0353 (.0401)	.0196 (.0224)
SELFEXLOG		-.0086 (.0692)	-.0019 (.0725)	-.0265 (.0697)
IQLOG		.2483* (.1796)	.2489* (.1782)	.2476* (.1793)
TEAVERLOG			-.0702 (.1584)	
TEAEXPLOG				.0055 (.0245)
R^2	.654	.665	.667	.666
Constant	.517	-.389	-.277	-.514

*Significant at 85% ($t \geq 1.5$) or 90% ($t \geq 1.7$).

**Significant at 95% ($t \geq 2.0$).

***Significant at 99% ($t \geq 2.8$).

[a]Regression coefficient: standard error of coefficient is in parentheses.

[b]Model 5 is not included since TEADEG has only one value for these students.

TABLE VIII

Effects on Mathematics Posttest Scores for Sixth Grade Boys with Linear and Cobb-Douglas (Log) Models

Variable	Model 1	Model 2	Model 3	Model 4[b]
		Linear models		
MB	.7836***[a] (.1096)	.7691*** (.1153)	.7628*** (.1174)	.7711*** (.1160)
CAISES	.0060** (.0027)	.0042* (.0030)	.0057* (.0042)	.0060* (.0038)
SELFEX		.1723 (.1396)	.1896 (.1455)	.1966 (.1437)
IQ		.0026 (.0111)	.0047 (.1173)	.0026 (.0111)
TEAVER			-.0054 (.0108)	
TEAEXP				-.0171 (.0213)
R^2	.606	.624	.627	.631
Constant	1.196	.886	1.027	.840
		Cobb-Douglas (log) models		
MBLOG	.6730*** (.1015)	.6685*** (.1354)	.6609*** (.1706)	.6612*** (.1056)
CAISESLOG	.0555* (.0313)	.0481* (.0366)	.0377 (.0435)	.0499* (.0375)
SELFEXLOG		.1023* (.0726)	.0907 (.0736)	.1057* (.0710)
IQLOG		.0876 (.2143)	.0901 (.2214)	.0856 (.2058)
TEAVERLOG			-.0071 (.1439)	
TEAEXPLOG				-.0213 (.0218)
R^2	.565	.593	.588	.600
Constant	.393	.136	.074	.035

*Significant at 85% ($t \geq 1.5$) or 90% ($t \geq 1.7$).

**Significant at 95% ($t \geq 2.0$).

***Significant at 99% ($t \geq 2.8$).

[a]Regression coefficient; standard error of coefficient is in parentheses.

[b]Model 5 is not included since TEADEG had only one value for these students.

APPENDIX

The tables in this appendix contain the correlation matrix and means and standard deviations for the independent variables used in the regression equations of the linear models. The tables are for students receiving CAI and the stratification by grade and by sex is maintained.

Insert Tables A.1 - A.4 About Here

TABLE A.1

Means and Standard Deviations and Correlation Matrix for Variables:

Fifth Grade Girls with CAI

Variable	Mean	S.D.	Correlation coefficients						
			MB	CAISES	SELFEX	IQ	TEAVER	TEAEXP	TEADEG
MB	3.91	.82	1.0000	.0643	.1492	.2477	-.0940	-.2250	.0293
CAISES	85.00	37.68		1.0000	.2675	.0767	-.0518	.1243	.4592
SELFEX	1.62	.63			1.0000	.0345	.0027	-.0183	.0589
IQ	86.86	10.07				1.0000	-.0027	-.0971	.0892
TEAVER	62.65	16.51					1.0000	.2865	-.4193
TEAEXP	12.83	9.77						1.0000	.3513
TEADEG	.42	.49							1.0000

TABLE A.2

Means and Standard Deviations and Correlation Matrix for Variables:

Fifth Grade Boys with CAI

Variable	Mean	S.D.	Correlation coefficients						
			MB	CAISES	SELFEX	IQ	TEAVER	TEAEXP	TEADEG
MB	3.54	.82	1.0000	.1976	.1786	.3752	-.0068	.0053	.0493
CAISES	79.92	42.57		1.0000	.1580	.0511	-.1886	-.0350	.2189
SELFEX	1.53	.75			1.0000	-.0106	.0681	.0136	-.0311
IQ	84.13	9.18				1.0000	.0383	.0053	-.0078
TEAVER	58.55	16.71					1.0000	.2927	-.3140
TEAEXP	11.68	10.05						1.0000	.4669
TEADEG	.43	.49							1.0000

TABLE A.3

Means and Standard Deviations and Correlation Matrix for Variables:

Sixth Grade Girls with CAI

Variable	Mean	S.D.	Correlation coefficients					
			MB	CAISES	SELFEX	IQ	TEAVER	TEAEXP
MB	3.84	1.01	1.0000	.0576	.1893	.5737	.0335	-.2428
CAISES	59.25	36.44		1.0000	.3799	.0729	.8244	.5825
SELFEX	1.38	.73			1.0000	.0087	.4527	.5696
IQ	85.92	11.18				1.0000	.1155	.0764
TEAVER	71.07	16.74					1.0000	.5196
TEAEXP	6.69	5.88						1.0000

TABLE A.4

Means and Standard Deviations and Correlation Matrix for Variables

Sixth Grade Boys with CAI

Variable	Mean	S.D.	Correlation coefficients					
			MB	CAISES	SELFEX	IQ	TEAVER	TEAEXP
MB	4.17	.85	1.0000	-.1524	.2178	.2875	-.1074	-.0807
CAISES	60.16	34.68		1.0000	.4618	-.0987	.7286	.6778
SELFEX	1.41	.76			1.0000	.1873	.4447	.4537
IQ	84.83	8.88				1.0000	.1264	-.0870
TEAVER	73.35	13.74					1.0000	.5700
TEAEXP	5.91	6.12						1.0000

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